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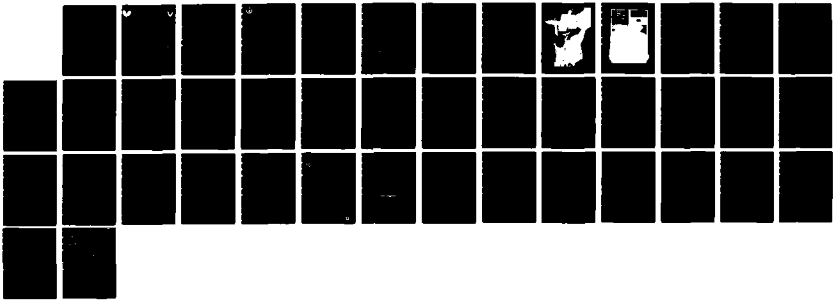

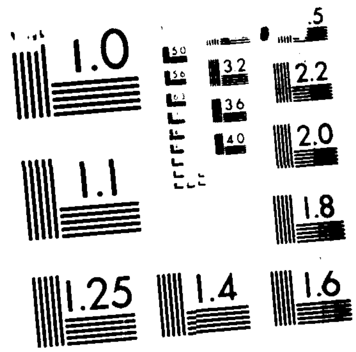

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TECOM PROJECT (TRMS) NO. 7-CO-MT7-AP1-001

REPORT NO. USACSTA-6338

US ARMY MATERIEL COMMAND

METHODOLOGY INVESTIGATION

FINAL REPORT

AUTOMATIC MAGNETIC RECORDING BORESCOPE

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DAJUN SONG

ENGINEERING DIRECTORATE

U.S. ARMY COMBAT SYSTEMS TEST ACTIVITY
ABERDEEN PROVING GROUND, MD 21005-5059

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Commander
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FOR THE COMMANDER:

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A new improved magnetic recording borescope was designed, constructed and evaluated. This borescope used two hall-effect sensors to detect the magnetic leakage field associated with cracks in magnetized ferromagnetic material. The borescope can inspect any cannon tube from 90-mm to 8 inches in diameter.

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FOREWORD

This investigation was performed by the U.S. Army Combat Systems Test Activity (USACSTA) at Aberdeen Proving Ground (APG), MD as part of the U.S. Army Materiel Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures, or prototype equipment (in mechanical, chemical, or nondestructive testing) to ensure efficient inspection methods for materiel/material procured or maintained by U.S. Army Materiel Command.

This project was initiated by Dr. Alfred L. Broz to modernize a magnetic recording borescope developed at the Army Materials Technology Laboratory (AMTL) and used at APG for the inspection of cannon tubes. Most of the precontract award effort was performed by Dr. Broz. Special recognition should be given to Mr. Harold P. Hatch for his technical assistance during early phases of this project. Both Dr. Broz and Mr. Hatch are now with the Army Materials Technology Laboratory, Watertown, MA. Special recognition should be given to Mr. H. S. Silvus, Jr. of Southwest Research Institute for his design of the automatic magnetic recording borescope, later modifications, and troubleshooting expertise.

SECTION 1. SUMMARY

1.1 BACKGROUND

During firing, the bore of a gun tube is subjected to a number of adverse conditions including high mechanical stress, high temperature, surface abrasion, corrosive gases, etc. The combined action of these conditions deteriorates the gun tube material. A critical result of such deterioration is formation of fatigue cracks originating on the bore surface and propagating outward through the wall material. When first formed, such cracks may not be of great significance, but as they propagate and become larger they create a safety hazard. Although advances in gun tube materials and manufacturing processes have resulted in substantial decreases in the deterioration rate, deterioration and the attendant safety hazard still exist.

APG, in collaboration with Watervliet Arsenal, has developed an improved system for nondestructive inspection of gun tube bores employing magnetization of the ferromagnetic gun tube material (fig. 1.1-1 and 1.1-2). Various versions of gun tube inspection systems with increased functional capabilities have been built. However, even the most recent model of the magnetic recording borescope (MRB) had less capability than desired and had performance limitations which decreased system effectiveness. This project was initiated to overcome these limitations and to increase system capability.

Performance requirements were written for the procurement of two MRB instrumentation systems, one for use at APG and the other at Watervliet Arsenal, NY. Valuable operator experience with the shortcomings of the existing MRB unit at APG served as input to the technical data package (TDP). The expertise of AMTL personnel who designed recent versions of the MRB was also incorporated. After procurement, the instrumentation was evaluated for durability, maintenance requirements, human factors, and reliability. The MRB will be used to inspect all various caliber cannon tubes within the 90-mm to 8-inch range.

Figure 1.1-1. Longitudinal drive and storage assembly.

1.1 (Cont'd)

Figure 1.1-2. Control console.

1.2 OBJECTIVES

The objectives of this project were to develop an improved magnetic recording borescope, verify the capabilities of the MRB, and determine its durability, maintenance requirements, and reliability. Initially an effort to develop crack depth, signal amplitude correlation data was to be performed; however, the sponsor AMTL and USACSTA agreed that more benefit would be gained by using available funds to perform the entended on-line evaluation.

1.3 SUMMARY OF PROCEDURES

A list of the shortcomings of the previous MRBs was compiled. Recommendations were solicited from AMTL, Watervliet, and other personnel knowledgeable of magnetic inspection techniques. A technical data package (TDP) was prepared for an R&D contract. The contract was let and monitored. A design review was performed. The final instrumentation was checked out by measuring performance parameters against procurement requirements. The instrumentation was placed on-line, inspecting 105-mm and 120-mm gun tubes for approximately 4 years. During this time, failures were analyzed and corrected, some by replacing components, some by redesign.

1.4 SUMMARY OF RESULTS

Compiling a list of shortcomings of the old MRB led to development of the set of requirements for the new MRB listed in paragraph 2.1. The main shortcomings were: (1) The detector head scanning assembly had a tendency to rotate as much as 45 to 90° as it traversed the length of a gun tube. This interfered with determining the radial position of a detected crack. (2) The defect detection signal was very noisy. Most of the noise was introduced by the scanning head electrical contact brushes. (3) The MRB was unable to inspect the entire interior surface of a gun tube. (4) Two completely separate scanning heads were required to cover the range of gun tubes from 90 mm to 8 inches in diameter. (5) The MRB detector head was rate dependent. This made the defect signal a function of detector velocity as well as crack size. All these shortcomings were eliminated by the new MRB.

The results of the initial checkout of the new MRB were obtained from the comparison of inspection system performance against the requirements stated in paragraph 2.1. The new MRB successfully met all the requirements except for the ability to inspect a 90-mm cannon tube. However, after installation of a small shim on the probe assembly, the requirement was met.

During the on-line evaluation of the MRB, there were 32 malfunctions. In eight instances, the longitudinal position sensor became clogged with dirt and failed to keep track of the position of the probe assembly. In seven instances, the storage position microswitch became bent and failed to stop the inspection head assembly at the proper position. In six instances, the friction drive roller failed to push the inspection head assembly through the forcing cone or through a gun tube. In three instances, the voltage regulator on the inspection head power supply board failed and had to be replaced. In three instances, the rotary transformer driver board had to be adjusted to eliminate unstable conditions in the signal channels. It was modified to eliminate this problem. Twice the inspection probe retract cable frayed or broke and had to be replaced. Once a bad solder joint generated noise in the radial channel. A loose setscrew caused the connections on the rotary transformer to break. Finally, one of the Hall-effect sensors failed and was replaced during the on-line evaluation.

All of the MRB malfunctions occurred during the early part of the evaluation. There were no failures during the entire last year of this project.

1.5 ANALYSIS

The results of the initial evaluation indicate a greatly improved magnetic recording borescope has been developed. All of the shortcomings inherent in the old MRB have been eliminated. The malfunctions that occurred during the on-line evaluation were analyzed and the MRB was redesigned to correct reoccurring problems. Performing without a malfunction for over a year indicates that all the bugs have been eliminated and the MRB now is very reliable.

1.6 CONCLUSIONS

a. The new MRB represents the state-of-the-art in nondestructive testing equipment for the inspection of cannon tubes.

b. The shortcomings of the old MRB have been eliminated. Determining the radial position is no longer a problem and the high frequency noise has been eradicated. The entire interior surface of a gun tube can be inspected.

c. The new MRB greatly improves the quality of cannon tube inspections. Crack size location can be more accurately determined.

d. The new MRB is more cost efficient. Total inspection time has been reduced to less than 25 minutes.

e. Although the MRB had many malfunctions during the early portion of the on-line evaluation, these problems were corrected and the system has since demonstrated a high degree of reliability.

f. The maintenance requirements for the MRB are minimal. A once-a-year maintenance check-up is all that is necessary.

g. The MRB has not proven to be very durable when utilized in a nonlaboratory environment. Most of the problems experienced during the evaluation can be attributed to the shock and vibration it experienced when being moved around the shop. Few malfunctions occurred after a decision was made to keep the MRB in a fixed location and to bring the cannon tubes to it.

1.7 RECOMMENDATIONS

a. The MRB should continue to be part of the nondestructive evaluation of cannon tubes both at Watervliet Arsenal and APG.

b. Larger wheels should be used to support the console and drive assembly to reduce shock and vibration when moving the instrumentation in the shop environment.

c. A permanent cover is needed to shield the driver roller from dust and dirt during the storage time between inspections.

d. A new type of electrical power cable cover is needed to house the wiring between the console and the drive assembly, one that is flexible and will not come apart.

e. When a method to produce artificial cracks that are truly representative a real cracks is developed, a project to evaluate crack-size determination should be initiated.

SECTION 2. DETAILS OF INVESTIGATION

2.1 DETAILED REQUIREMENTS FOR NEW MRB

a. The MRB had to be capable of nondestructively testing the entire interior surface of a wide variety of cannon tubes presently used in the Department of the Army using magnetic flux leakage techniques.

b. The MRB had to determine the required magnetization level for inspection.

c. The scanning head had to incorporate two detectors. One detector had to be capable of measuring the tangential component of the magnetic flux leakage. The other detector had to be capable of measuring the normal component of the magnetic flux leakage.

d. The detectors used in the scanning head could have been either rate insensitive or rate sensitive; however, if the detectors were rate sensitive, either adequate provision had to be made to eliminate the effects of the velocity of the detector in interpretation of the magnetic signatures obtained or a constant ($\pm$0.25%) detector velocity had to be provided.

e. The detectors used in the scanning head had to maintain a constant ($\pm$10%) lift-off distance from the inner circumference of the inspected tube. For those areas containing lands and grooves, the land surface was considered the tube surface.

f. The probe assembly had to maintain detector lift-off spacing.

g. An extended skid assembly had to house the detectors to reduce or eliminate detector contact instability encountered when scanning severely eroded areas of fired gun tubes.

h. The detector mounting had to assure perpendicularity ($\pm$1°) of the detector to the bore surface, and constant alignment ($\pm$1°) of the detector head with the bore surface during change-of-slope conditions within the chamber neck, forcing cone, and origin of rifling portions of the gun tube.

i. The scanning head had to circumferentially rotate the detectors over the interior surface of the gun tube at an appropriate rpm and maintain either constant ($\pm$0.25%) rotational speed or constant ($\pm$0.25%) detector velocity throughout the inspection procedure.

j. The scanning head had to provide a reference signal for each revolution of the detectors of adequate magnitude (1 to 2 V) and duration (1 to 5 ms) to provide a trigger pulse for an oscilloscope display.

k. The location of the source of the reference pulse had to be physically identified.

l. The location of the reference pulse around the circumference of the gun tube had to be at a convenient location such as 12, 3, 6, or 9 o'clock.

2.1 (Cont'd)

m. For each system, a scanning head or heads had to be furnished which would cover the entire range of diameters of gun tubes required to be inspected (90-mm to 8-in.).

n. The scanning head had to utilize rotary transformers or other brushless signal coupling devices to the extent possible and feasible to reduce or eliminate the need for slip ring and brush type signal couplers.

o. During the entire inspection procedure, the scanning head's central axis had to coincide with the central axis of the gun tube to within ± 0.05 inch.

p. During the entire inspection procedure, the orientation of the reference pulse's circumferential location within the gun tube could not rotate or change by more than $\pm 0.5°$.

q. An axial traversing mechanism had to translate the scanning head through the gun bore.

r. The traversing mechanism had to be adaptable to the range of tubes required to be inspected.

s. The traversing mechanism had to allow inspection of 100% or any critical portion of a given gun bore.

t. The traversing mechanism in combination with the scanning head had to provide a continuous helical scan of the gun bore with a minimum of 30% overlap between circumferential passes of the detectors.

u. The traversing mechanism in combination with the scanning head had to provide a repetitious circumferential pass of the detectors over the tube interior surface with the traversing mechanism stopped any place within the tube.

v. The traversing mechanism had to allow locating the detector anywhere within the tube to ± 0.10 inches measured from the rear of the tube.

w. The traversing mechanism had to traverse in either direction.

x. A control console had to be provided for the MRB system containing a control panel, a monitoring oscilloscope, signal processing equipment, and power supplies.

y. The control panel had to include controls for the scanning and traversing mechanisms and allow control of entire system power; start, stop and direction of traversing mechanism; selection of detectors in scanning head one at a time for display purposes; and start and stop of scanning mechanism.

z. Signal processing equipment had to be included in the control console and provide appropriate amplification, filtering, and signal processing to provide electrical signals and data sufficient to allow at least four different data display or presentation options.

2.1 (Cont'd)

aa. The signal processing equipment had to provide the same type of signals provided by the existing MRB instrumentation.

bb. There had to be two additional outputs of the MRB to facilitate display of the output in a graphic or slow scan video format. These outputs had to be TTL compatible parallel digital binary numbers or analog voltages.

cc. Two output signals were needed, one proportional to the angular position of the detector head and the other proportional to the linear position of the present angular scan.

dd. A monitoring oscilloscope was required to present signal amplitude versus angular position at a given longitudinal position within the bore.

ee. The sweep speed of the oscilloscope had to be adjustable to coincide with the rotational speed of the detector head.

ff. The oscilloscope had to provide a dual delaying sweep to allow easy and accurate measurements of magnetic signatures.

gg. A recording camera was required to provide permanent records of magnetic signatures displayed on the monitoring oscilloscope.

hh. A strip chart recorder capable of recording the peak signal detected versus the longitudinal position in the tube was required.

ii. The defect detection principle had to be based on magnetic flux leakage techniques which utilize the residual field in previously magnetized tubes.

jj. The system had to detect a crack type defect 0.125 inch in length and 0.10 inch in depth oriented within $\pm 20°$ of the longitudinal axis of the tube located anywhere on the interior surface of the tube.

kk. The system had to detect the artificial cracks and service-induced cracks of 0.10 inch and deeper in depth.

ll. The maximum inspection time for a tube could not exceed 45 minutes including set-up time for the system.

mm. The system had to detect the crack type defects, mentioned earlier, in fired tubes which contain heat checking (pattern of surface cracks formed by extreme alternate rapid heating and cooling of the metal surface) up to 0.05 inch in depth.

nn. The system had to detect all cracks earlier detected by the previous MRB instrumentation.

2.2 DESCRIPTION OF MRB

The Magnetic Recording Borescope System (MRBS) is comprised of two major components, a longitudinal drive and inspection head assembly and a control console. The longitudinal drive assembly is attached by a system of clamps to the breech end of the gun tube being inspected. The inspection head, which is normally stored inside the cylindrical structure of the longitudinal drive assembly, is then pushed through the cannon-tube bore by a lightweight I-beam longitudinal drive member. The inspection head contains two hall-effect magnetic detectors which are oriented to sense the radial and tangential components of magnetic flux at the surface of the cannon-tube bore. These detectors are mounted on a centrifugal arm such that they scan a circular path along the surface of the cannon-tube bore; however, when the longitudinal drive is engaged, the hall-effect detectors scan a helical pattern on the cannon-bore surface. In addition to the sensors, the inspection head contains a rotary-drive system, an inertial vertical reference, a rotary-position encoder, and sensor support electronics.

The control console houses the control panel, an oscilloscope, a strip-chart recorder, control logic, signal-conditioning circuitry, and system power supplies and provides storage for the longitudinal-drive adaptors. Pushbutton switches on the control panel facilitate selection of oscilloscope input signals and actuation of longitudinal and rotary motion of the inspection head. Indicators show various types of detection and alarm events.

The inspection head is supported by a roll-around vertical-column stand. The control console is comprised of a two-bay rack-type cabinet mounted on casters.

2.2.1 Typical Signal Channel

There are two signal channels in the MRBS, one for the tangential component of magnetic flux and one for the radial component. These two channels are essentially identical and will be described simultaneously. Figure 2.2-1 is a block diagram of the signal conditioning channel. The sensor is a hall-effect device positioned near the bore surface of the cannon tube being inspected. Physical orientation of the hall-effect element determines whether it is sensitive to the tangential or radial component of magnetic flux. Sensor output is increased in magnitude by a factor of 1000 in the preamplifier. Then the signal is used to frequency modulate a high frequency carrier which in turn modulates the light output of an infrared emitting diode. The light beam signal is received by a photodiode which forms the second part of this optical link (to be described more fully later). The output from the optical link passes through high and low pass filters which limit the signal bandwidth (1 Hz to 1 kHz). A level regulator operates upon the filter output to produce a signal which has constant average value. This processed signal passes through a buffer and becomes the system analog output signal. Additionally, the regulated signal passes through an active full-wave rectifier which drives (1) a level detector which delivers a defect alarm whenever the level-regulated signal exceeds a present threshold and (2) a peak detector which delivers a slowly decaying output signal responsive to the peak value of the signal.

2.2.1 (Cont'd)

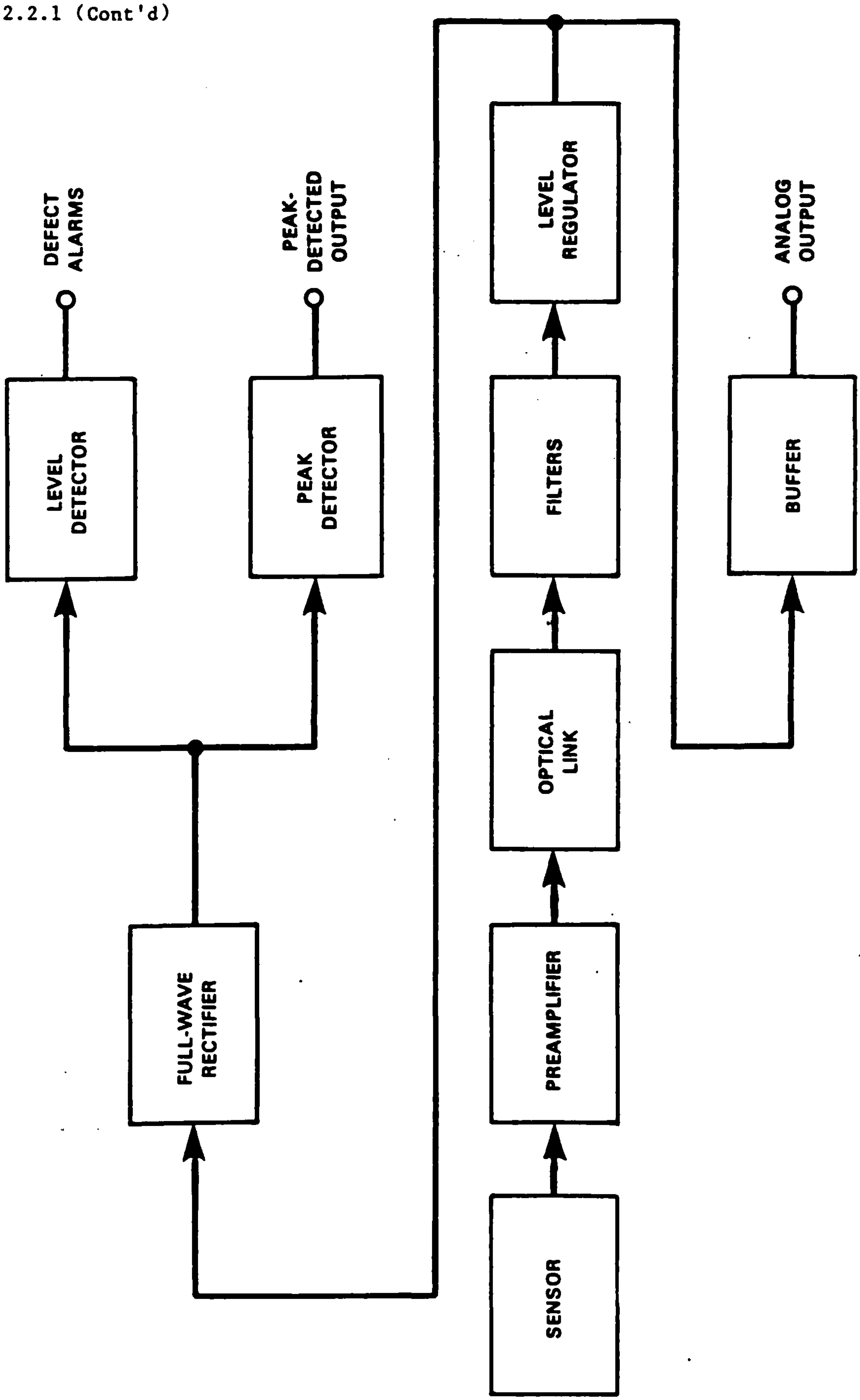

Figure 2.2-1. Block diagram of signal conditioning channel.

2.2.2 Optical Link

Since the signal which represents the detection of a defect in the cannon tube originates in a subsystem which is rotating and this signal must eventually be displayed on a stationary part of the system, at some point the signal must transition from a rotating component to a stationary component. In the old model of the MRB, the signal was transitioned using carbon brushes which added noise to the signal. To eliminate noise, the new MRB transmits the signal to a stationary component over a light beam.

The optical link transmits two simultaneous signals across the rotary interface between the rotating and stationary parts of the inspection head. As illustrated in the block diagram of Figure 2.2-2, the optical link comprises two modulators which accept inputs from the two sensors and deliver frequency-modulated carriers at 300 kHz and 450 kHz, respectively. The two carriers are added in a linear mixer and, by way of a driver, modulate the radiant output of an infrared-emitting diode. Modulated radiation from the infrared-emitting diode falls on a silicon photodiode, the output of which is increased in magnitude by a preamplifier. The two frequency components of the preamplifier output signal are separated by band-pass filters centered about 300 kHz and 450 kHz, respectively. The output signals encounter identical processing which includes demodulation, filtering to remove carrier noise from the desired signal, and output buffering to drive the signal-conducting cable to the control console. The voltage gain of the optical link from the modulator input to the buffer output is approximately unity.

2.2.2 (Cont'd)

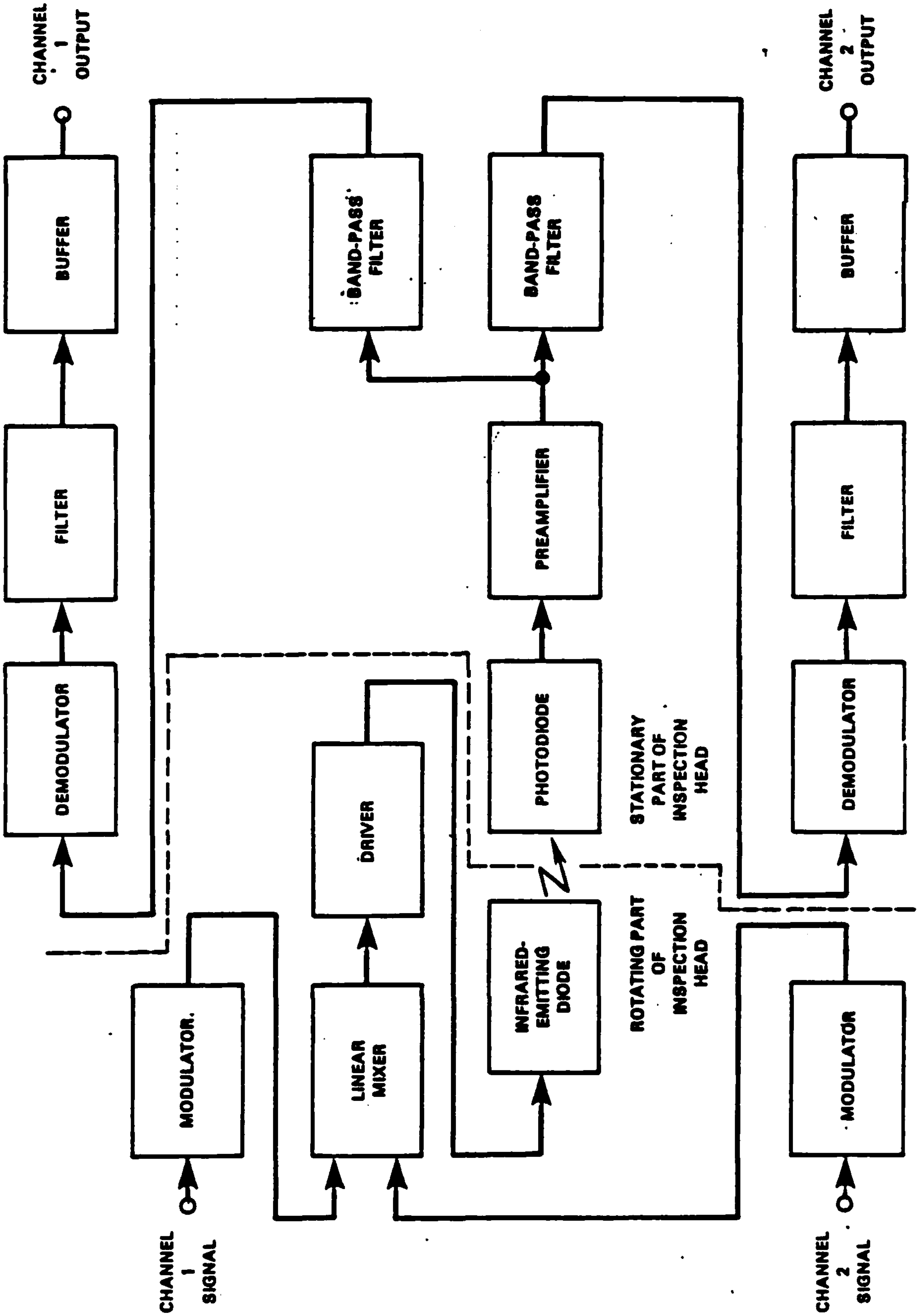

Figure 2.2-2. Block diagram of optical link.

2.2.3 Level Regulator

Since cannon tubes are long and vary in thickness, the residual magnetism implanted in the tube varies in strength along the length of the tube. This will affect the strength of the defect signal. To compensate for this variation in tube magnetization, the strength of the background flux is used to adjust the gain in the signal procesing circuits. This causes the amplitude of a crack signal to be independent of the position of the crack in the cannon tube.

The block diagram of the level regulator is illustrated in Figure 2.2-3. The input signal is simultaneously applied to the numerator input of an analog divider and to the input of an active full-wave rectifier. A low-pass filter at the rectifier output greatly attenuates signal frequency components at frequencies above 5 Hz, thereby producing a DC signal proportional to the average value of the input signal. The rectified and filtered signal is applied to the denominator input of the analog divider. Whenever the average value of the input signal increases, effective voltage gain through the analog divider is decreased proportionately so that the average value of the output signal remains constant. Similarly, if the average value of the input signal decreases, effective voltage gain through the analog divider increases so that the average value of the output signal still remains constant; however, if a short-duration pulse, such as the generated by a crack in the cannon-tube bore, appears in the input signal, its contribution to the average is relatively small so that the pulse passes through the analog divider at the prevailing voltage gain. By maintaining the average value of the output signal constant, a single threshold setting of the defect alarm level detector in the signal channel accommodates a wide range of signal-strength variations. A switch is provided to defeat the automatic level regulator, and a manually operated control which facilitates setting a fixed value of signal-conditioning channel gain is included: the manual mode of operation may be used for inspecting smooth-bore tubes or for emphasizing a signal of interset.

In addition to the described functions, the level regulator also contains a level detector which monitors the control signal at the low-pass filter output. If this signal level falls below a preset threshold, a low-flux alarm signal is generated. This will alert inspection personnel of an improperly magnetized cannon tube.

2.2.3 (Cont'd)

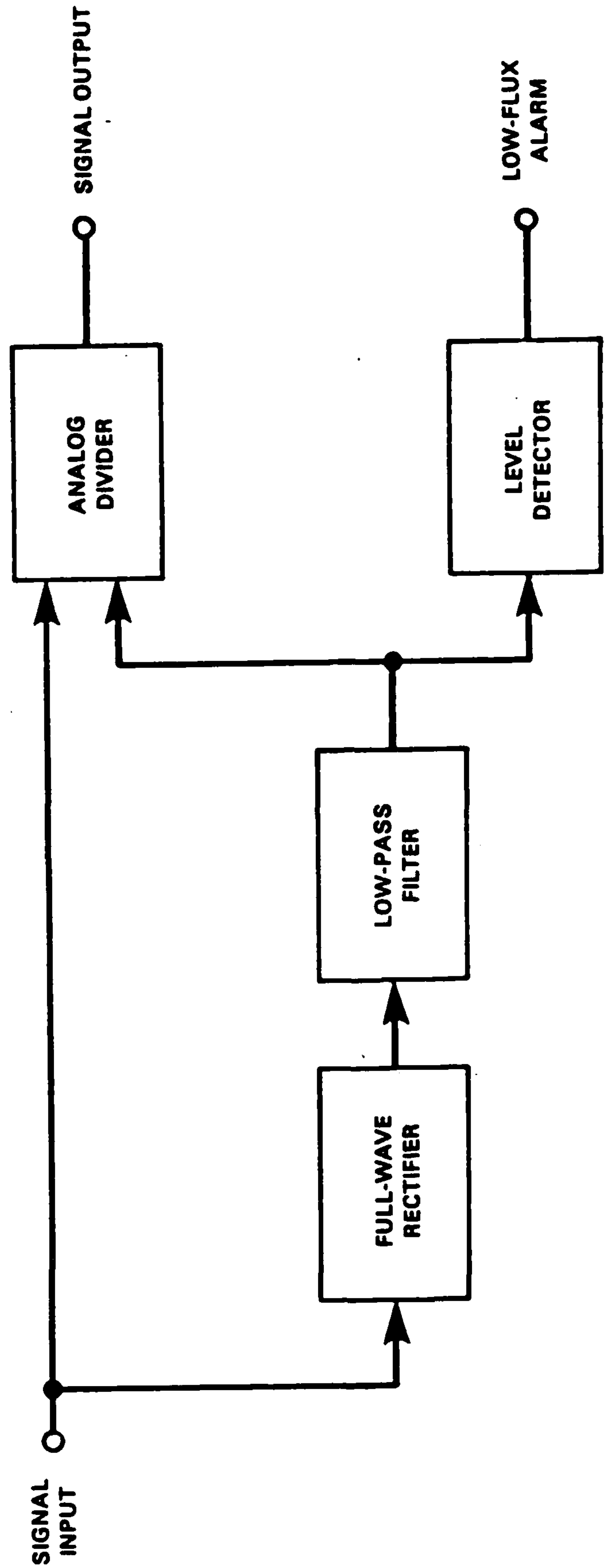

Figure 2.2-3. Block diagram of level regulator.

2.2.4 Rotary Position Determination

In order to determine the angular position of a detected crack in a cannon tube, it is necessary to keep track of the rotating probe assembly as it moves along the tube. Rotary position of the MRB sensors is determined by a 1024-count shaft encoder mounted on a gravitational reference. The shaft encoder output includes two quadrature count signals and a 6 o'clock time mark. These signals pass through differential line drivers and through cables to line receivers located in the control console (fig. 2.2-4). The two quadrature count signals pass through a quadrature detector which effectively multiplies the count frequency by a factor of 4. The output of the quadrature decoder clocks a 12-bit binary counter, the outputs of which pass through buffers to the rotary position digital outputs and through a digital-to-analog convertor to produce the rotary position analog output. Additionally, the quadrature decoder output drives a frequency-to-voltage convertor which generates a tachometer signal used in feedback control of the rotary-drive motor to maintain a constant rotational velocity.

The 6 o'clock time mark signal passes through a buffer to an output connector on the rear panel of the control console and to the external trigger input of the oscilloscope. This signal corresponds with the bottom of the cannon tube.

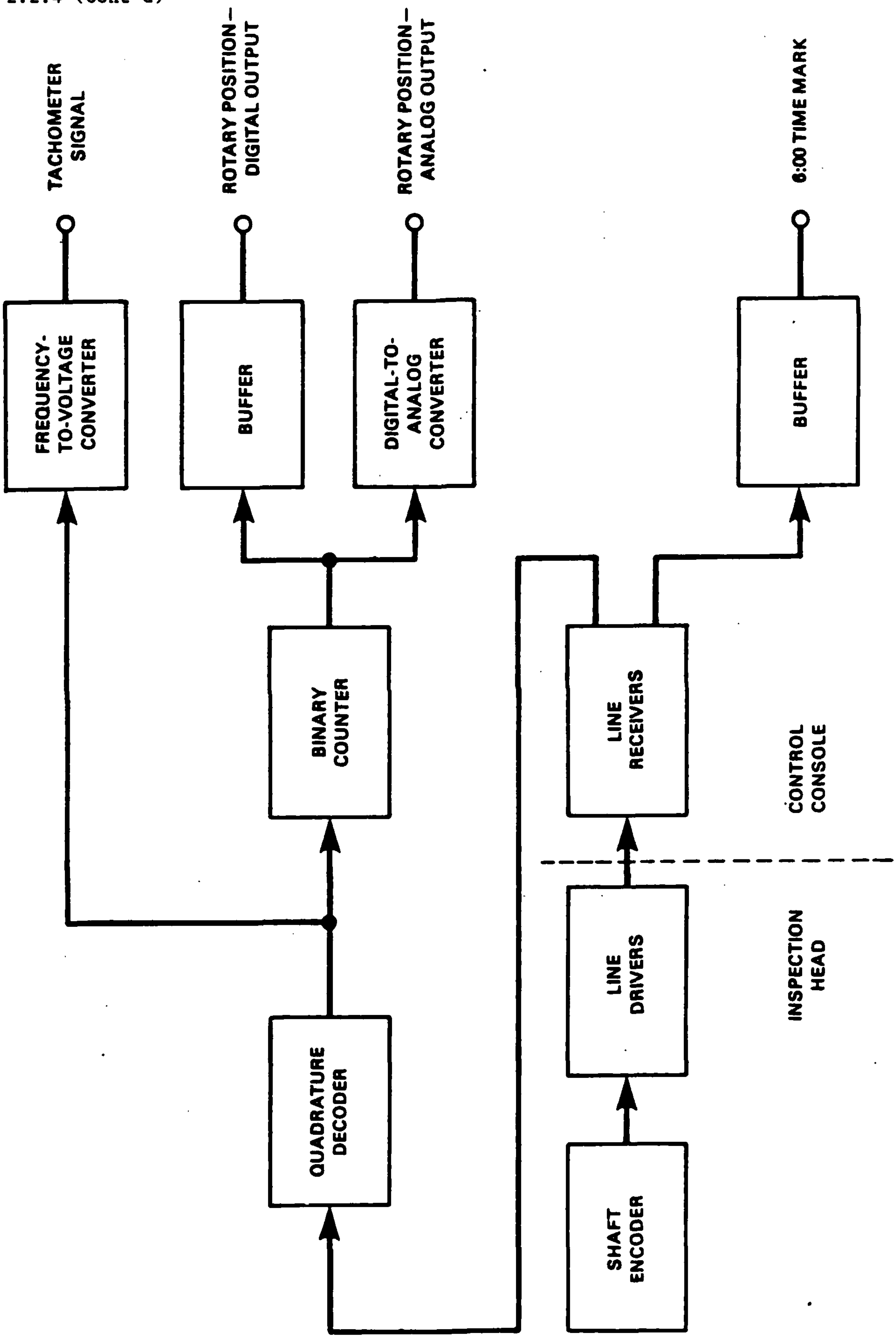

Figure 2.2-4. Block diagram of rotary position indicator.

2.2.5 Longitudinal Position Determination

In order to determine the probe distance down-the-tube when a crack is detected, one flange of each longitudinal-drive member I-beam is perforated with 0.100-inch wide slots on 0.200-inch centers. Two infrared-emitting diodes transmit radiant energy through these slots to associated silicon phototransistors. The infrared-emitting-diode and phototransistor pairs are situated so that two quadrature signals are generated as the I-beam moves longitudinally. As illustrated in the block diagram of Figure 2.2-5, sensor output signals pass through differential line drivers and cables to line receivers located in the control console. A quadrature decoder interpolates the received signals by a factor of 4, thereby producing 0.05-inch resolution. The quadrature decoder output simultaneously drives an up-down decimal counter and an up-down binary counter. Outputs of the binary counter pass through buffers to the longitudinal position digital outputs and through a digital-to-analog convertor to the longitudinal position analog output. Outputs of the up-down decimal counter pass through BCD-to-7-segment code convertors to the longitudinal position digital display located on the console control panel. Additionally, up-down decimal counter outputs drive one set of a 12-bit digital magnitude comparator. The other input of the magnitude comparator is derived from the tube-size decoder which comprises a read-only memory (ROM) programmed with the maximum inspectable lengths of the various cannon tubes. Whenever the count in the up-down digital counter equals or exceeds the output of the tube-size decoder, a longitudinal drive limit signal is generated; this signal stops the drive motor. The tube-size decoder ROM receives as its input contact closures from three snap-action switches located at the forward end of the longitudinal-drive storage tube assembly. These switches are actuated by projections on the cannon-tube adaptors so that installation of an adapter to accommodate a specific cannon-tube caliber automatically sets the maximum longitudinal travel limit.

A manual mode for inputting the longitudinal scan limit is also provided. This mode is useful for inspecting nonstandard tube lengths.

2.2.5 (Cont'd)

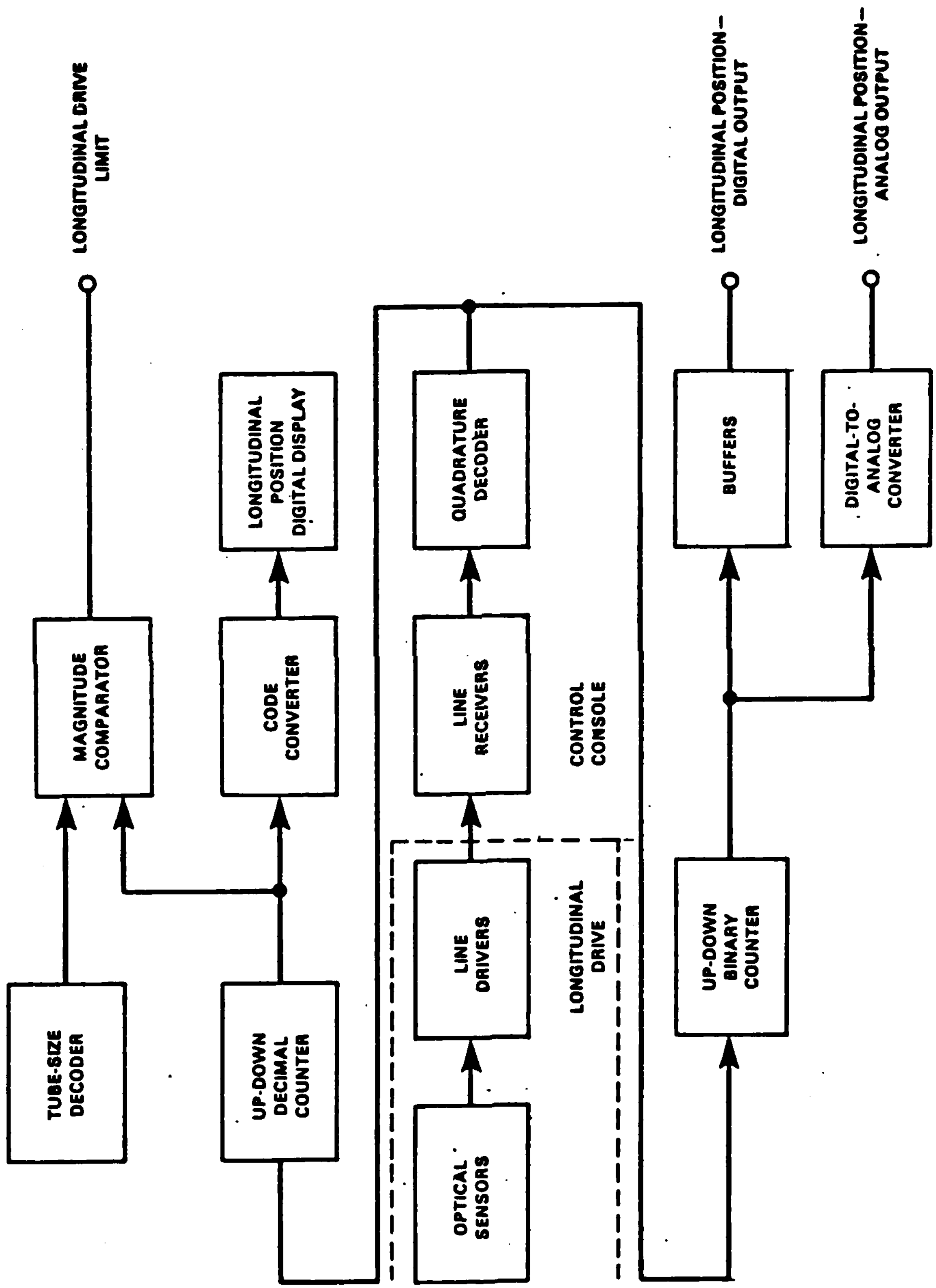

Figure 2.2-5. Longitudinal position indicator.

2.2.6 Alarm Circuits

Various alarm conditions occurring during operation of the MRBS generate either aural or visual indications, or both. The defect alarm signals generated in the signal channels, the low-flux alarm signals generated in the level regulators and certain limit switches produce alarm conditions as illustrated in block diagram form in Figure 2.2-6. Presence of one or more alarm signals is detected by the alarm decoder which actuates the appropriate alarm indicators. Individual lamps on the console control panel illuminate to indicate existence of the following conditions: (1) a defect signal in the tangential channel, (2) a defect signal in the radial channel, (3) low flux level in the tangential channel, (4) low flux level in the radial channel, (5) the inspection head has reached the far end of the cannon tube (i.e., scan limit), (6) another longitudinal drive member section required (i.e., longitudinal drive limit), and (7) the inspection head fully retracted in the longitudinal drive storage tube (i.e., storage limit). Additionally, the aural annunciator emits: (1) a series of tone bursts at a slow repetition rate when either the longitudinal drive or scan limit occurs, (2) a series of tone bursts at a fast repetition rate when low flux exists in either channel, and (3) a continuous tone burst when a defect signature is detected in either channel. Priority of use of the aural annunciator is as follows: (1) the longitudinal drive or scan limit takes precedence over either of the other two indications; (2) in the absence of a longitudinal drive or scan limit, low flux takes precedence over a defect indication; and (3) in the absence of the other two alarm conditions, presence of a defect in either channel will cause the annunciator to sound. An alarm inhibit switch is provided on the console control panel to shut off the aural alarm for the defect and low-flux indications; however, actuation of the alarm inhibit switch does not prevent the aural alarm from sounding when the longitudinal drive member or scan limit occurs.

2.2.6 (Cont'd)

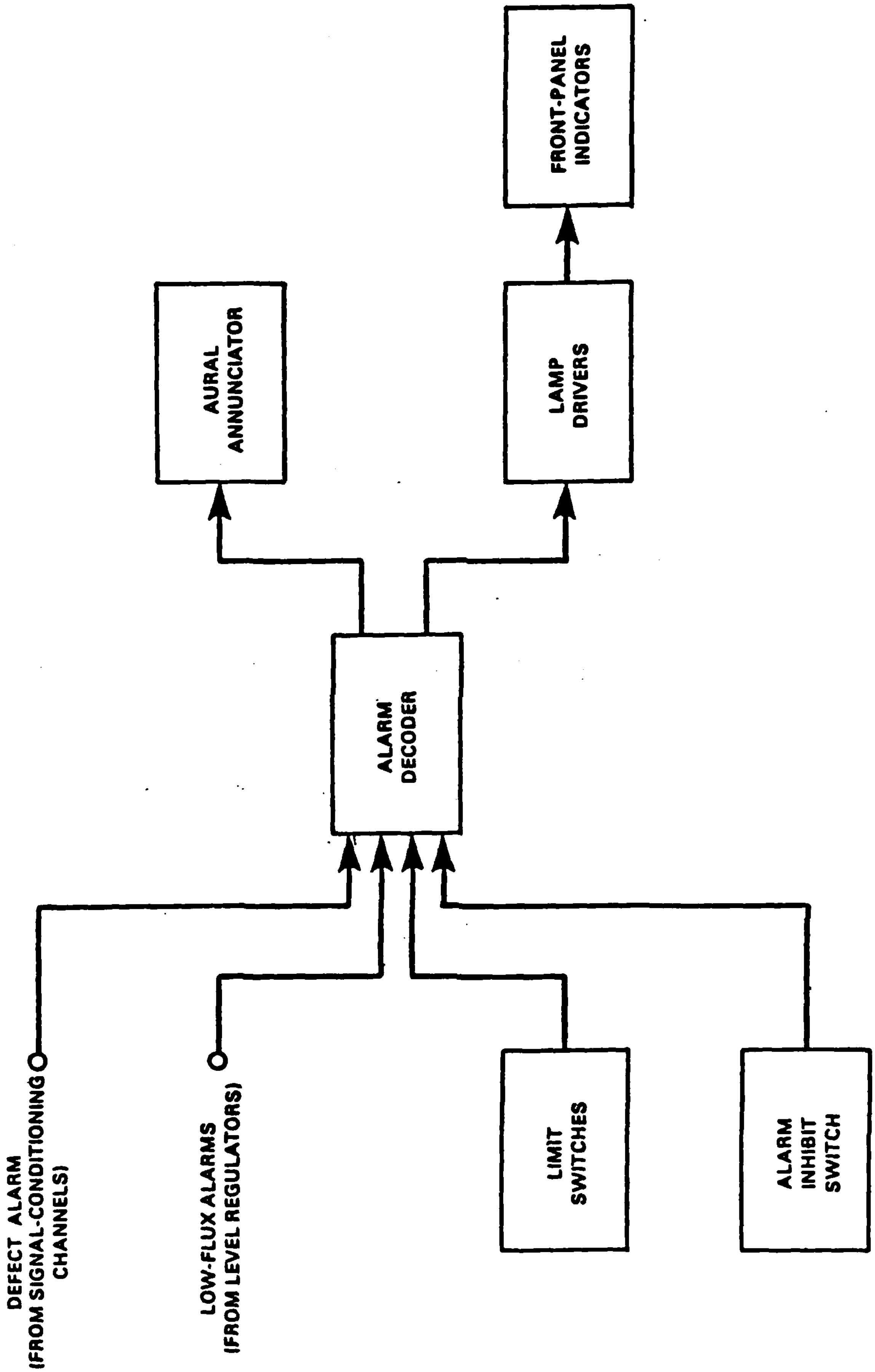

Figure 2.2-6. Alarm circuits.

2.2.7 Rotary Transformer and Inspection Head Power Supplies

Because there is electronic circuitry in the rotating part of the inspection head, it is necessary to transmit power across the rotary interface between the stationary and rotating parts of the inspection head. A rotary transformer, which has its primary winding on the stationary part of the inspection head and its secondary winding on the rotating part of the inspection head, is used to magnetically couple the necessary energy across the rotary interface. Because there is (1) an appreciable air gap in the transformer and (2) a need to minimize physical size, the rotary transformer is excited at high frequency (i.e., approximately 16 kHz). Transformer excitation is provided by a power amplifier as shown in Figure 2.2-7. A square-wave generator operating at approximately 16 kHz provides the signal source for the power amplifier. Output of the square-wave generator is integrated to produce a triangular wave which, in turn, is rounded at the peaks by a waveform shaper to produce a satisfactory approximation to a sine wave at the power amplifier input.

The rotary transformer has two secondaries, one of which is center tapped. The center-tapped secondary feeds a full-wave bridge rectifier and capacitive-input filter to produce bipolar DC outputs which drive a positive and negative tracking voltage regulator which, in turn, delivers positive and negative 15 VDC to the inspection head circuits.

The other secondary of the rotary transformer feeds a full-wave bridge rectifier and capacitive-input filter which provides the DC input to a current regulator which, in turn, supplies the excitation current to the hall-effect sensors.

2.2.7 (Cont'd)

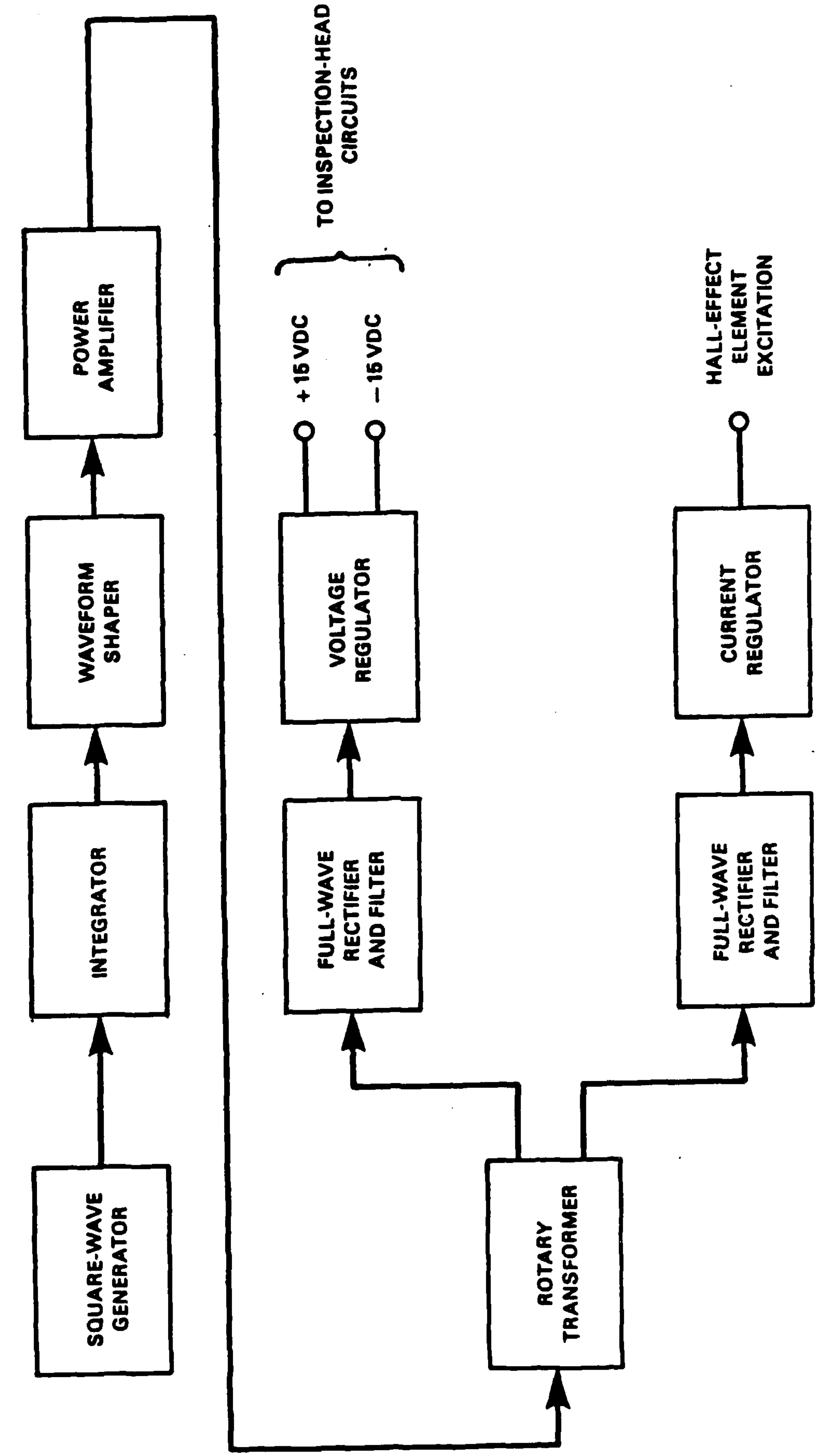

Figure 2.2-7. Rotary transformer and inspection head power supplies.

2.3 INITIAL CHECKOUT AND ON-LINE EVALUATION

2.3.1 Initial Checkout

The initial checkout of the MRB was performed in September 1980 by verifing that the instrumentation met all the requirements stated in paragraph 2.1. Only one problem was encountered during the checkout. The MRB probe assembly did not retract enough to inspect 90-mm gun tubes (the smallest diameter tubes to be inspected by the MRB). The contractor, Southwest Research Institute (SWRI) provided a shim for the probe assembly which corrected the problem. During the checkout, several desirable features were recognized that were not required by the original contract: (1) Additional adapters were needed. Two new gun tubes had been added to those which must be inspected; these additions occurred after the original specifications for the MRB were written. (2) As required by the contract, the signal conditioners in the MRB employ automatic gain control to compensate for the changes in strength of the magnetization of the gun tube being inspected. For certain applications, such as inspection of the new smooth-bore tube, it was desirable to have fixed gain in the signal-conditioning channels, and (3) the maximum inspectable length was preprogrammed in a pair of read-only memories. An alternate means of setting inspection length would be useful for foreign and nonstandard tubes. All these features were provided by a contract modification with SWRI.

2.3.2 On-Line Evaluation

After completion of the contract modification in April 1981, the MRB was placed in service in Building 525 at APG. During the following 2 years, there were several malfunctions. Some were diagnosed and corrected in-house but many required services of SWRI.

Seven times, the MRB failed to rotate in the storage position, which is necessary for the detection of the test signal to verify proper operation of the defect detection circuits before the inspection of the cannon tube. The cause was determined to be a bent microswitch which failed to close and prevented the probe assembly from rotating. At first, it was thought that the switch was being hit too hard when the actuator on the returning assembly missed the slow-down switch due to misalignment caused by vibration of the system. However, it was later determined that the switch was being bent while the MRB was transported from one section of the work area to another. Maintaining the housing assembly nose-down while moving the MRB prevented pressure on the switch and no further bending occurred.

There were several incidents when the longitudinal drive assembly slipped and failed to push the inspection head assembly through the tapered section of the gun tube adapter. The cause was determined to be dust and oil deposited on the friction drive roller from the shop atmosphere. Several cleaners were tried. Household dishwashing detergent was determined to be the best cleaner. It left the roller surface with a higher coefficient of friction. This problem was prevented from reoccurring by draping a cloth over the drive roller when not in use.

Intermittent noise occurred in both signal channel circuits. The strength of this noise completely masked the normal signal obtained from the rifling in the gun tube. This noise was traced to fraying of the probe retract wire which

2.3.2 (Cont'd)
returns the probe assembly to its rest position when the assembly is not rotating. This wire was made of fine stainless steel strands. The wire became frayed and the strands would short-out components on the inspection head power supply board as the board rotated. This problem was corrected by replacing the stainless steel wire with a nylon cable. The nylon cable only has a life expectancy of one year, however, and needs to be periodically replaced.

The radial and tangential signals would also become unstable at times. In three incidents this was traced to a bad voltage regulator on the inspection head power supply board. At other times, the rotary transformer driver board needed adjustment. Replacement of the voltage regulator or adjustment of the drive board corrected the problem. The three voltage regulators failed early in the on-line evaluation. The final replacement has lasted 2 years without a malfunction. The rotary transformer driver board was modified by SWRI to have twice the output capacity. The new board has operated satisfactorily since installation in July 1985.

A high-level intermittent noise in the radial channel could be introduced by lightly tapping the circuit board in the inspection head. This was traced to a bad solder joint in the preamplifier board. Repair of the solder joint corrected the problem.

Many times the longitudinal position indicator would stop advancing even though the inspection head was still traveling down the gun tube. If the inspection head were inside the gun tube, loss of this function would only cause: (1) a delay in determining the longitudinal position of a crack if one were detected during the inspection and (2) a failure to automatically stop the inspection head when it reached the end of the gun tube. However, if this failure occurred while the inspection head were in the forcing cone before it reached the gun tube, the probe assembly would not rotate and no inspection would be possible. This problem was always traced to dirt clogging the openings for the infrared silicon phototransistors and the IR emitting diodes. Spraying these small openings with magnetic recording head cleaner would normally correct the problem, but the useful time between cloggings became shorter. This problem was finally corrected by modifying the longitudinal sensor assembly so that the apertures in front of the infrared emitting diodes and the phototransistors were filled with a transparent material to prevent entry of oil and dirt.

A complete loss of radial and tangential signals was traced to broken connections on the rotary transformer. The wires were broken because the setscrew in the transformer shaft vibrated loose and allowed the primary half of the transformer to rotate and pull loose the connections. Resoldering the connections and tightening the setscrew corrected the problem. The setscrew did not fail in 2 additional years of operation.

A loss of the tangential signal was traced to a nonfunctioning Hall-effect sensor in the probe assembly. Since the probe assembly is a molded component, the entire assembly was replaced.

Although not a problem that prevented or interferred with the operation of the MRB, the connecting cables between the console and the longitudinal drive assembly were covered with a quick snap-on outer covering that would come apart and expose the interconnecting wiring. No covering could be found that would be flexible enough to replace the original snap-on type. However, this cable will be recovered when a suitable replacement is found.

SECTION 3. APPENDICES

APPENDIX A - MATERIALS TESTING TECHNOLOGY DIRECTIVE AND PROPOSAL

DEPARTMENT OF THE ARMY Mr. Champion/lt/283-2170
HEADQUARTERS. U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND. MARYLAND 21005

DRSTE-ME

3 DEC 1976

SUBJECT: Directive, Automatic Magnetic Recording Borescope Inspection of Cannon Tubes (90mm to 8 inch), TRMS No. 7-CO-MT7-AP1-001

Commander
US Army Aberdeen Proving Ground
ATTN: STEAP-MT-S
Aberdeen Proving Ground, MD 21005

1. Reference is made to:

a. DARCOM Regulation 702-14, dated 27 December 1973.

b. Procurement/Work Directive, Julian Date 6315, from AMMRC to APG (Incl 2).

2. This letter, STE Forms 1188 and 1189 (Incl 1), and the work directive (reference 1b) constitute a directive for the subject work under the Materials Testing Technology Program administered by AMMRC.

3. All work and reporting will be accomplished under the guidance provided by AMMRC. Monthly fiscal reports and semi-annual status reports will be prepared in accordance with reference 1a and submitted directly to AMMRC with an information copy to this headquarters, ATTN: DRSTE-ME. Direct contact with AMMRC is authorized.

4. Attention is invited to the 30 June 1977 expiration date stated in reference 1b.

FOR THE COMMANDER:

2 Incl
as

FRANCES T. SMITH
Admin Asst. SGS

PROCUREMENT/WORK DIRECTIVE

TO: CPE, Aberdeen Proving Ground, ATTN: STEAP-MT-M, Mr. S. Tiragin, Aberdeen Proving Ground, MD 21005	APPROVED BY: R. B. CIRBY, Chief, Mat'ls Testing Tech Div	PAGE 1 OF PAGES	PRIORITY
FROM: Director, Army Materials and Mechanics Research Center, AMXMR-M, Watertown, Mass. 02172	AUTHOR: B. GILLIS, Comptroller	PROJECT NO.	
CMS TITLE/ITEM NOMENCLATURE: MIT Materials Testing Technology (MTT)	CUSTOMER ORDER NUMBER	PRON: A1-T-W635?-?1-AW-K2	
AMCMS CODE: 53970M6350	ACCOUNTING CLASSIFICATION: 21T2035 T6A 7022 P5397 S19-066		DATE DISP
QUANTITY ON ORDER	TARGET DATE FOR OBLIGATION: 6331	LOCAL USE: A77-25	

QUANTITATIVE AND CHANGE DATA

ELEMENT	U/M	QUANTITY	UNIT PRICE	TOTAL PRICE
a. PRIOR				
b. TOLERANCE USED				
c. INCREASE				$15,000.00
d. DECREASE				
e. CURRENT				$15,000.00
f. TOLERANCE				
21. REPORT CODE F			22. TYPE OF FINANCING C	

DESCRIPTION OF WORK AUTHORIZED/SPECIAL INSTRUCTIONS/INCLOSURES:

The following guidelines are given relative to the execution of these tasks:

a. Contracts for equipment and services are to be awarded within 6 months of acceptanc of this Order. Such contracts will not be awarded without prior approval of this Center.

b. Semi-annual technical and monthly fiscal reports will be supplied as specified in AMCR 702-14, dated 27 December 1973. Final reports are due within 90 days of expiration da

Automatic Magnetic Recording Borescope Inspection of Cannon Tubes (90mm to 8 inch)

Scope of Work: Valuable operator experience with the shortcoming of the two existing MRB u at APG and the expertise of AMMRC personnel who designed recent versions of the MRB will se as inputs to the preparation of a technical data package (TDP) for the procurement of two additional MRB instrumentation systems. After procurement, the instrumentation will be evaluated for durability, maintenance requirements, human factors and reliability. A prog will be initiated to develop crack depth-signal amplitude correlation data for cannon tube within the new MRB instrumentation system.

Expiration date of this order: 30 June 1977

The above items and conditions are satisfactory, are accepted as a Project Order Cost Reimbursable and the work or services will be performed as ordered herein.

PACKAGING, PACKING AND MARKING SHALL BE IN ACCORDANCE WITH:

DISTRIBUTION PATTERN — BASIC FACT CODE

CERTIFIED AVAILABILITY OF FUNDS OR ORDER ALLOTMENTS IN THE AMOUNT CITED

NOV 15 1975

(Date)

JOHN W. F. BUCKLAND

Finance & Accounting Officer

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P & P LEVEL — PACKING LEVEL

Incl 2

FY78
MATERIALS TESTING TECHNOLOGY
PROJECT REQUESTS

1. Project Title: Automatic Magnetic Recording Borescope Inspection of Cannon Tubes (90-mm to 8 Inch)

2. Amount: (In Thousands) $5.5 3. Date: 24 Mar 77

4. Installation: MTD, APG 5. Task No:

6. Proposed MTT Effort:

a. Army Problem - Current methods for crack detection in tube bores primarily depend on human operator interpretation of the interior surfaces utilizing visual/optical techniques. The black light borescope, which is the present method of bore inspection for smooth bore and rifled tubes, is a slow, monotonous and tedious process prone to operator fatigue and error. Fast, automatic detection of bore cracks would eliminate the "eye-brain" bottleneck and result in a cost savings, and higher reliability crack detection. The approximate time for manual black light borescope inspection of a gun tube varies between 2 and 4 manhours, depending on gun size and firing history. Automatic inspections should cut that time to less than 20 minutes - offering time savings of at least 50% for the tube. The feasibility of automatic quantitative crack detection with a Magnetic Recording Borescope (MRB) has been demonstrated. Improvements in electrical and mechanical design of the MRB system should allow its evaluation for eventual implementation as an inspection technique for evaluating discontinuities in gun tubes ranging in size from 90-mm to 8".

b. Proposed Solution - A technical data package (TDP) for the procurement of two MRB instrumentation systems is being prepared. Valuable operator experience with the short-comings of the two existing MRB units at APG are serving as input to the TDP. The expertise of AMMRC personnel who designed recent versions of the MRB will also be input to the TDP. After procurement, the instrumentation will be evaluated for durability, maintenance requirements, human factors and reliability. The MRB will be used to inspect all caliber cannon tubes within its range at APG. A program will be initiated to develop crack depth-signal amplitude correlation data for cannon tubes within the capability of the new MRB instrumentation system. The program should include MRB inspection and sectioning of tubes that develop significant discontinuities. If insufficient tubes with significent discontinuities are inspected, tubes will have to be prepared with "cracks". The combined results of this continued effort will be a TDP package for procurement of MRB instrumentation, and data sufficient for crack depth-signal amplitude correlation. This will allow implementation of the MRB as an inspection technique for evaluating cracks in gun tubes.

7. Detailed Scope of Work:

a. Outline of Investigation - The investigation will consist of a number of phases:

(1) Phase I - Evaluation of procured MRB instrumentation for durability, maintenance requirements, human factors and reliability.

(2) Phase II - MRB inspection of all tubes inspected at APG.

(3) Phase III - Implementation of program to develop crack depth-signal amplitude correlation data.

Phases I and II would be initiated in the first year of effort. Phase III would be initiated in the second year of effort. Phases II and III would be continued during the third year of effort.

b. Milestones & Accomplishment Dates :

Element	Date	% Effort	Cost
Evaluation of Instrumentation	Jul 78- Dec 78	8	$ 5,000
MRB Inspection piggybacking other inspections at APG	Jul 78- Dec 79	29	18,000
Crack-depth-signal amplitude correlation	Jan 79- Dec 79	63	40,000

c. End Products

(1) Evaluation of procured MRB instrumentation packages.

(2) Crack depth-signal amplitude correlation data.

(3) Recommendation for implementation of MRB instrumentation for inspection of cannon tubes.

8. Significant Prior R&D:

Magnetic recording borescope inspection systems for the inspection of cannon tubes have been designed and developed by AMMRC. A review of efforts up to and including 1971 is contained in AMMRC Report PTR 71-4. The feasibility of using the MRB for the inspection of Category II 175-mm gun tubes was demonstrated at APG in Report APG-MT-3725. A good correlation between the MRB signal and the cross-sectional crack path below the surface was established in that report. Because the feasibility of quantitative crack detection was demonstrated, smaller caliber gun/howitzer tubes (90 to 105-mm) were inspected. The system for the smaller calibers was similar to the one used for the 175-mm gun tube. It used a Hall Probe Detector in place of the induction type detector. Cracks or flaws were present only in modified 105-mm M68 gun tubes. The MRB was able to detect and locate most of the severe cracks. Insufficient data was available to correlate the depth of artifically or service-induced and propagated flaws. A number of shortcomings in the mechanical and electrical design of the MRB system were also noted. The MRB in its present form is used at this proving ground to evaluate discontinuities noted in black light borescope inspections. The inspector uses the MRB scan to help localize the area needing ultrasonic inspection. A technical data package for procurement of two new MRB instrumentation systems is currently being prepared at APG. Funds have been received to procure the new systems.

9. Savings/Benefits:

The approximate magnetic particle inspection time for cannon tubes, including black light borescope inspection, varies between 2 and 4 manhours and can extend to 8 manhours, depending on gun size and firing history. Automatic crack detection with a Magnetic Recording Borescope should reduce that inspection time by a least 50% per tube. The scope of the implementation of the MRB inspection technique would determine the yearly savings in manhours. A demonstrated capability of automatic quantitative crack detection should result in Army-wide implementation of the technique.

In addition to providing location and length of discontinuities in gun tubes, the MRB will also furnish information concerning the "severity" of depth of the discontinuities noted.

10. Implementation:

The NDT Section of the Physical Test Branch, MTD, Aberdeen Proving Ground, (Autovon 283-2876) will be responsible for implementation of project results. The Test and Evaluation Command's Operations Procedure (TOP) will be generated for performance of Test Evaluation Command testing.

11. Funding

	Prior	Budget	Future		
	FY77	FY78	FY79	FY80	FY81
R&D					
PEMA	140	5.5	44.5	13	0
OTHER (OMA, etc.)					

	Prior FY 77	Budget FY78	FY79	Future FY80	FY81
12. Detailed Cost Analysis: a. In-House					
(1) Engineering	0	5.5K	40K	13K	0
(2) Fabrication					
(3) Equipment					
(4) Travel			4.5		
Totals	0	5.5K	44.5K	13K	0

b. Contracts

(1) Scope - To obtain expertise of private industry in the design and fabrication of this specialized instrumentation.

(2) Breakdown

(a) Engineering	35K
(b) Fabrication	85K
(c) Equipment	0
(d) Travel	5K
Totals	125K

13. Addendums: None

14. Project Investigator

Dr. Alfred L. Broz
Autovon 283-4417
MTD, APG, MD

15. Administrative Actions:

a. Concurrence of responsible lab/div chief of individual organization preparing proposed task.

C, EM&A Div E. L. FOOTE

b. Concurrence of Responsible Product Assurance Representative (concurrence that task supports quality assurance).

C, M&I Div J. A. FEROLI

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